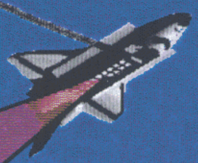
Topographic Map Generation from the Shuttle Radar Topography Mission C-Band SCANSAR Interferometry



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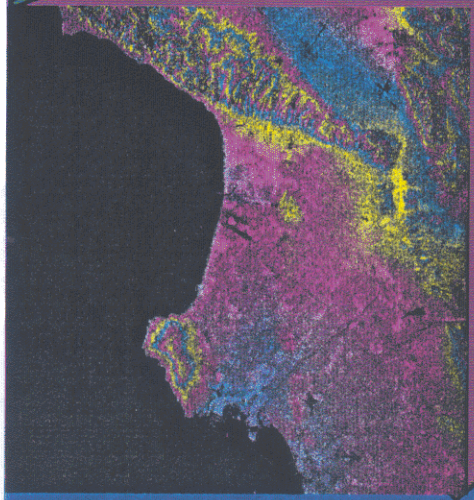

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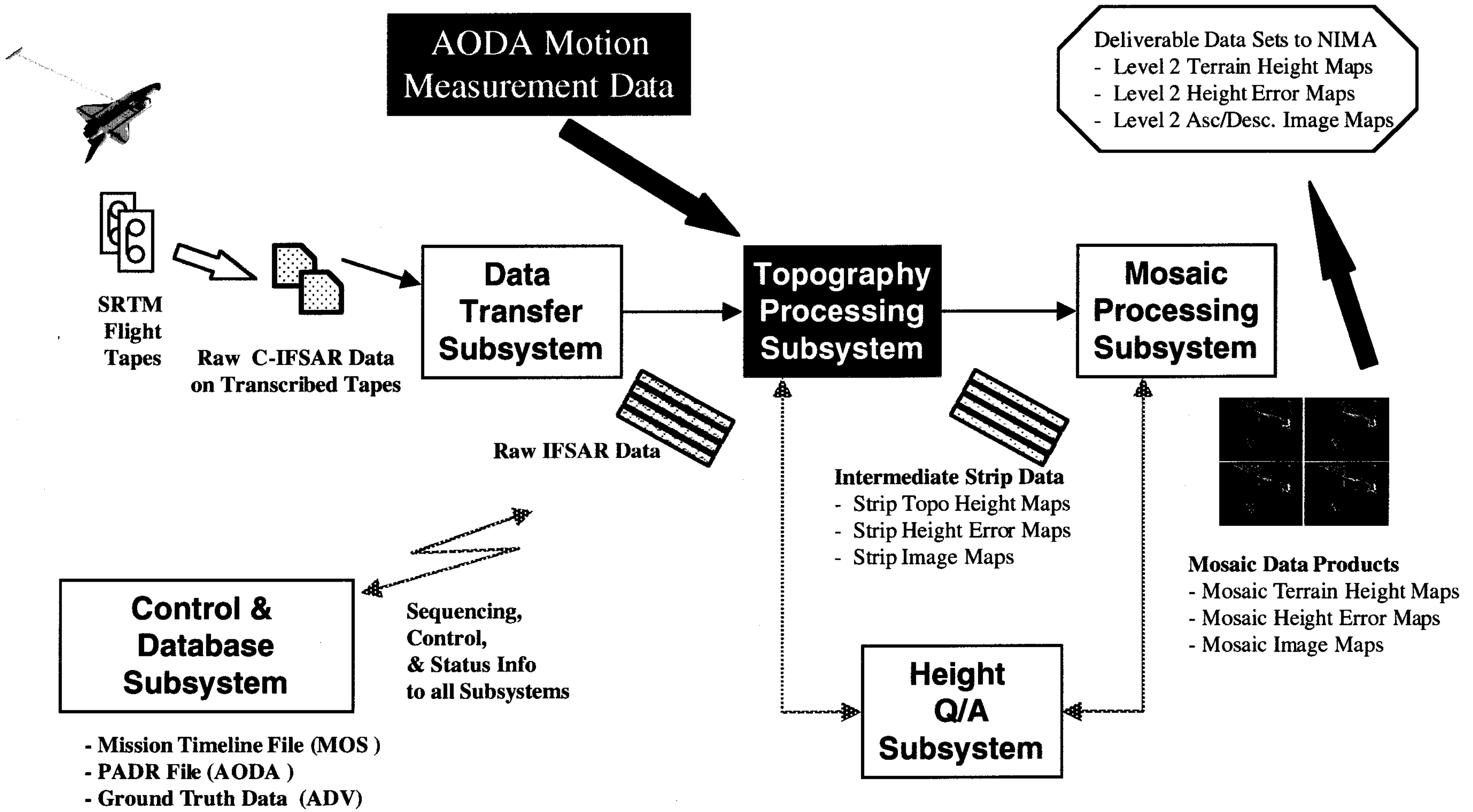
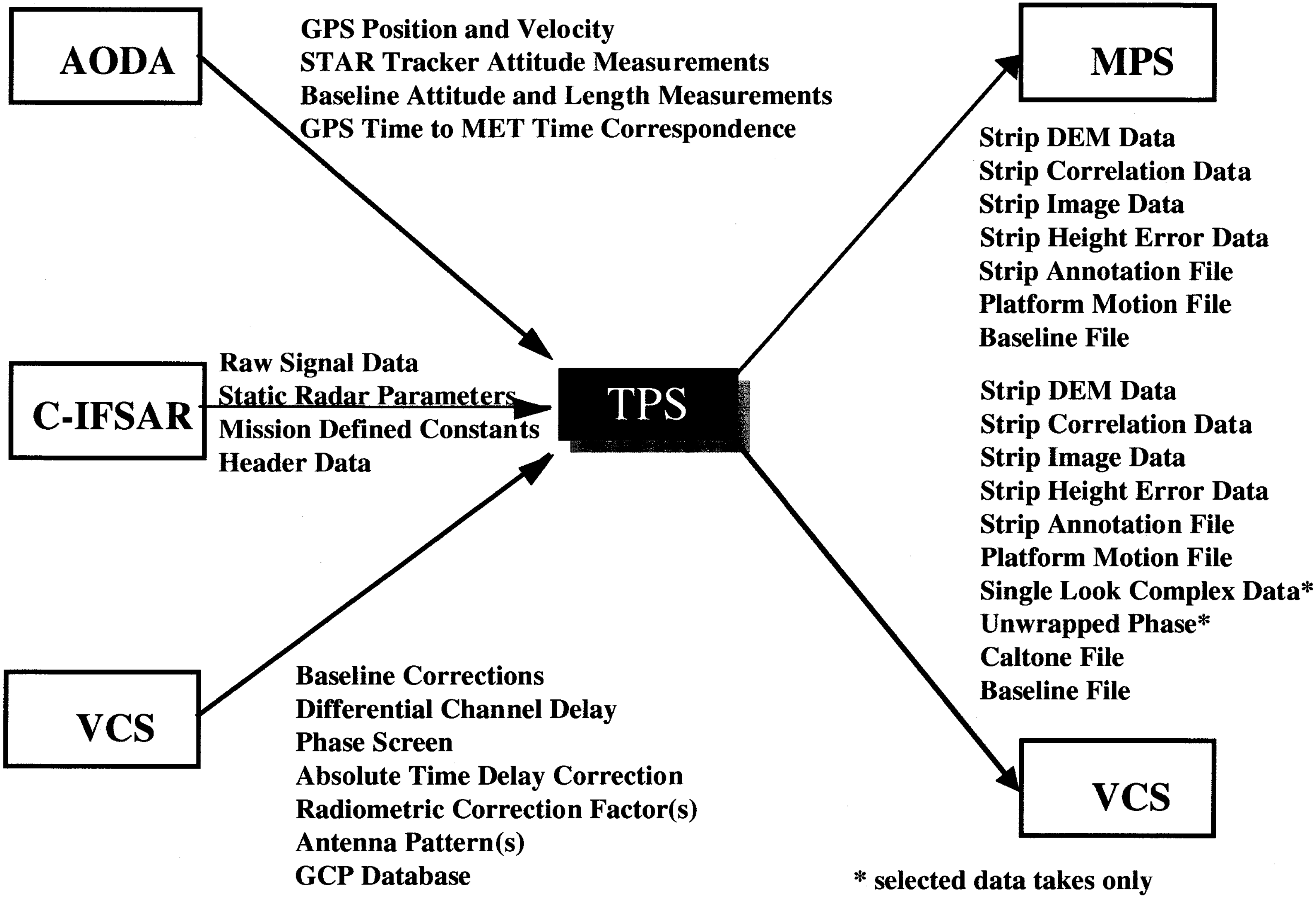
Overview

- SRTM Ground Processing System
- Preprocessing
- Image Formation
- Interferogram Generation
- Unwrapping
- Height Reconstruction
- Regridding
- Conclusions

SRTM Ground Data Processing System



TPS Interfaces



Topographic Processing System

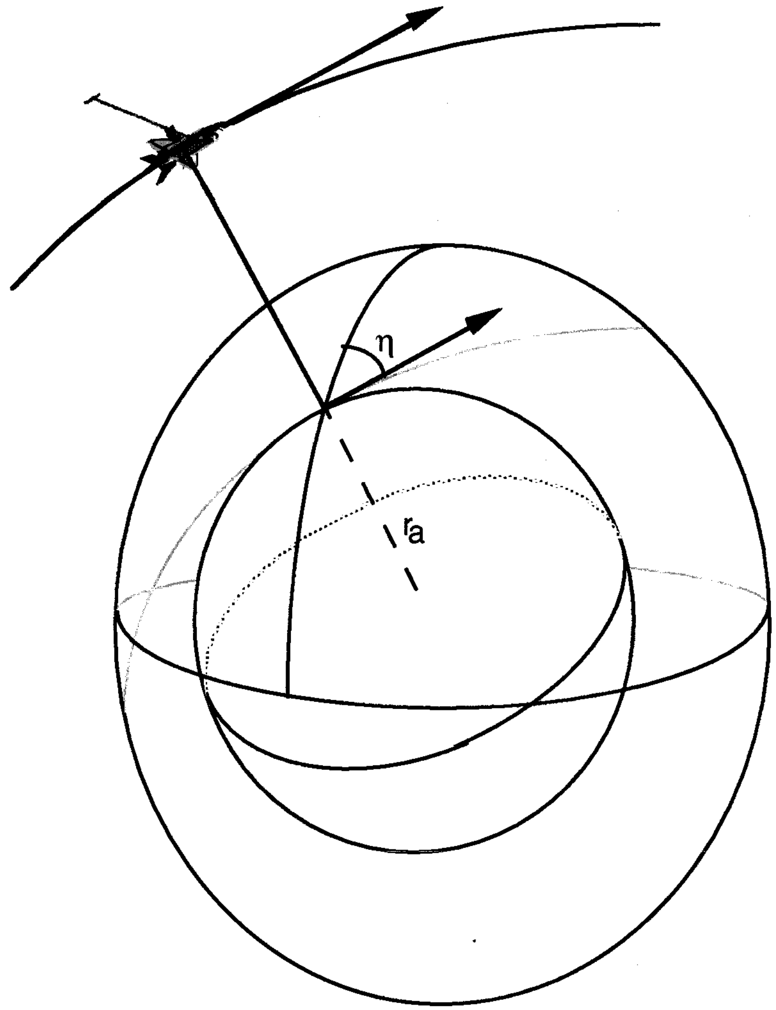
- TPS is composed of two major programs a Preprocessor (Globoprep) and the Processor (Globoproc)
  - The Preprocessor major functions are
    - Compute the SCH coordinates to use for each strip
    - Resample the AODA data to a constant along track spacing and convert all motion data in the desired coordinate systems
    - Generate the Processor command command file -
  - The Processor major functions are
    - Range compress and motion compensate the burst data
    - Burst level image formation and interferogram generation
    - Form combined interferogram from individual burst interferograms
    - Unwrap phase and determine the absolute phase
    - Inverse motion compensation
    - Reconstruct the heights and regrid to a uniformly spaced ground projection

The SCH Coordinate System

- The processor uses a coordinate system (sch) which is a spherical coordinate system that best approximates the ellipsoid in the along track direction.

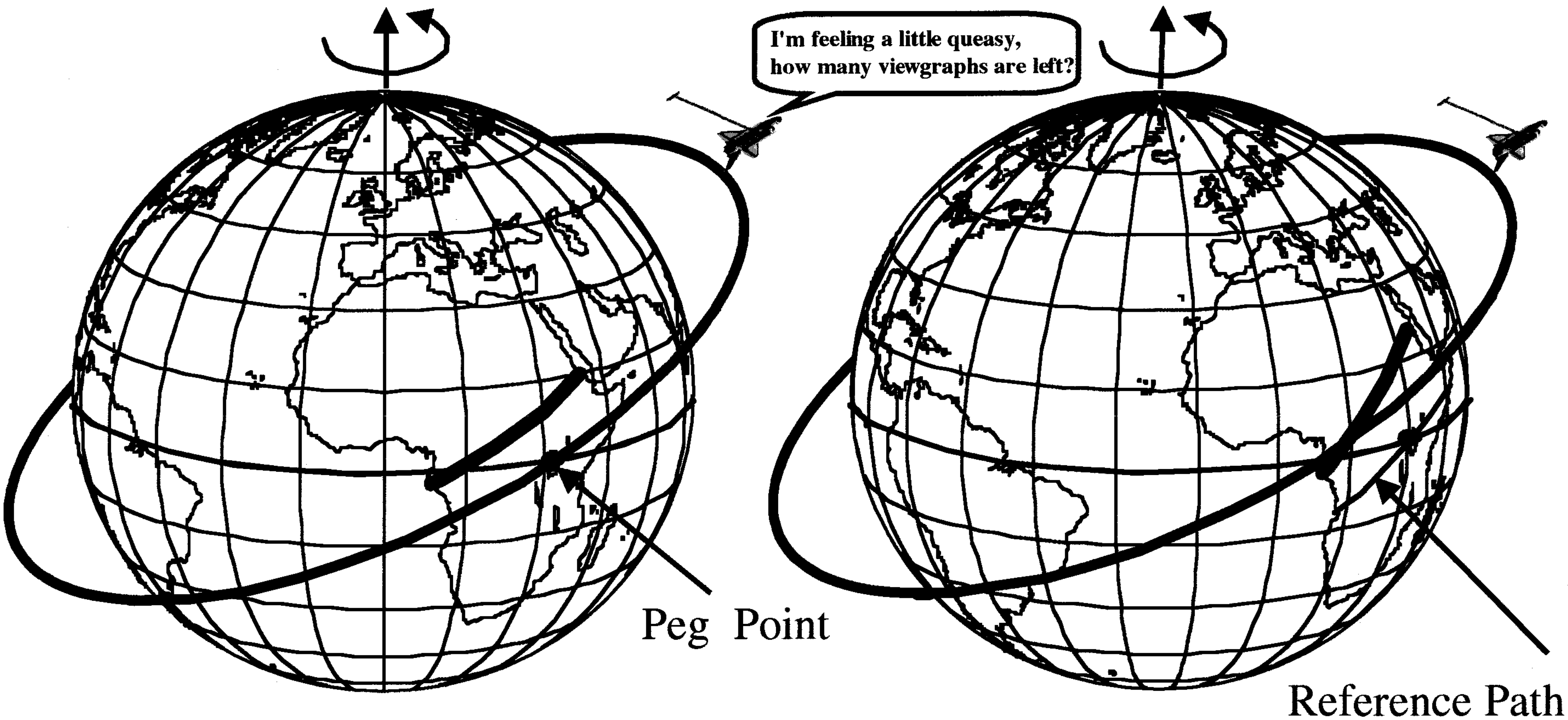
- This coordinate system is readily referenced to WGS-84 coordinates, provides a convenient and accurate means of parametrizing the flight path by distance, and provides a well defined coordinate frame for determining target position vectors from the phase data.

$$r_a = \frac{r_e(\lambda) r_n(\lambda)}{r_e(\lambda)\cos^2(\eta) + r_n(\lambda)\sin^2(\eta)}$$



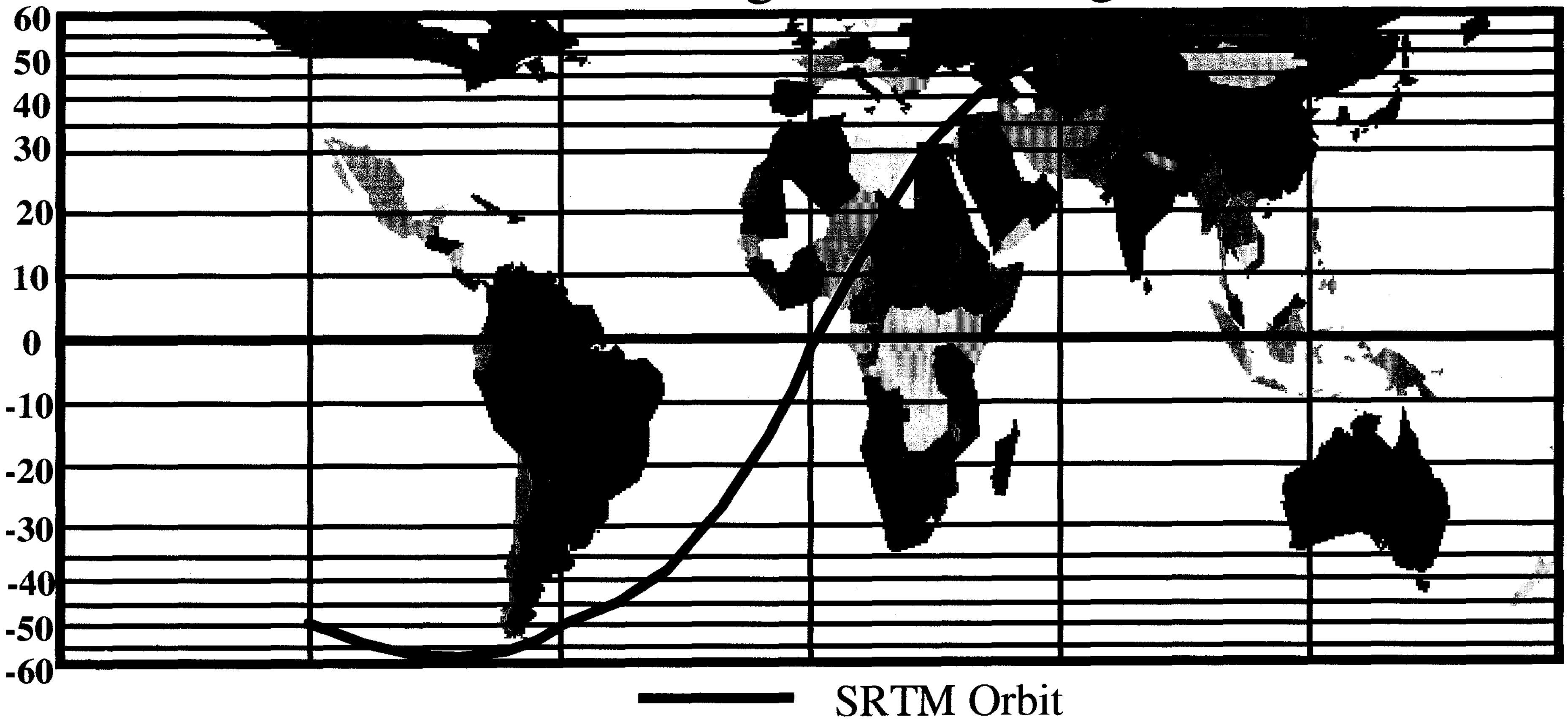
- η is sensor heading at peg point

Earth Rotation is an Annoyance



- If the earth did not rotate the projection of the orbit onto the earth's surface would be a "great circle" and the mapped swath would stay a fixed distance away from the SCH reference path. Because the earth rotates the mapped swath deviates from the reference path. The amount of deviation is a function of the distance from the peg point.

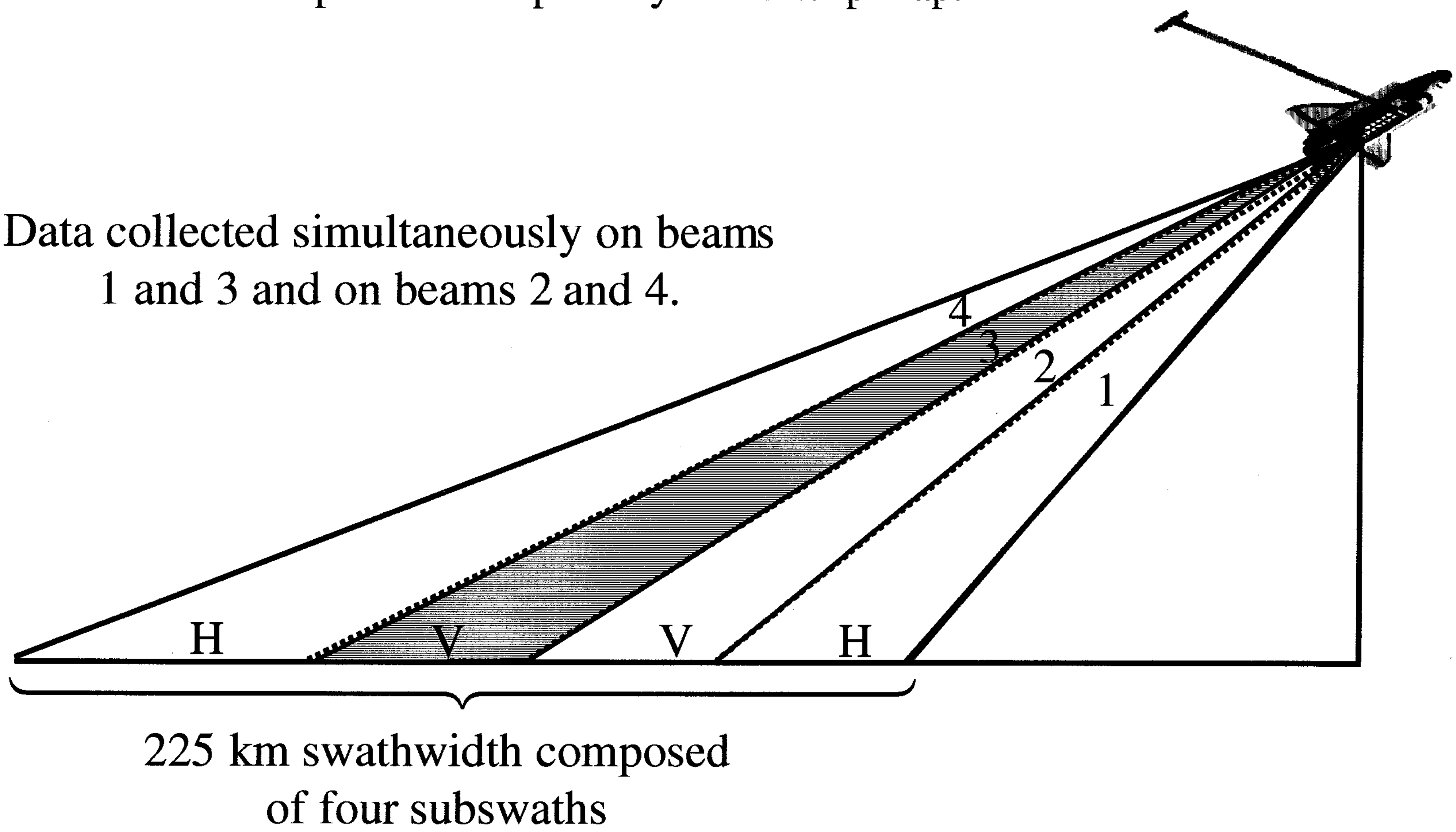
SCH Constant Peg Latitude Regions



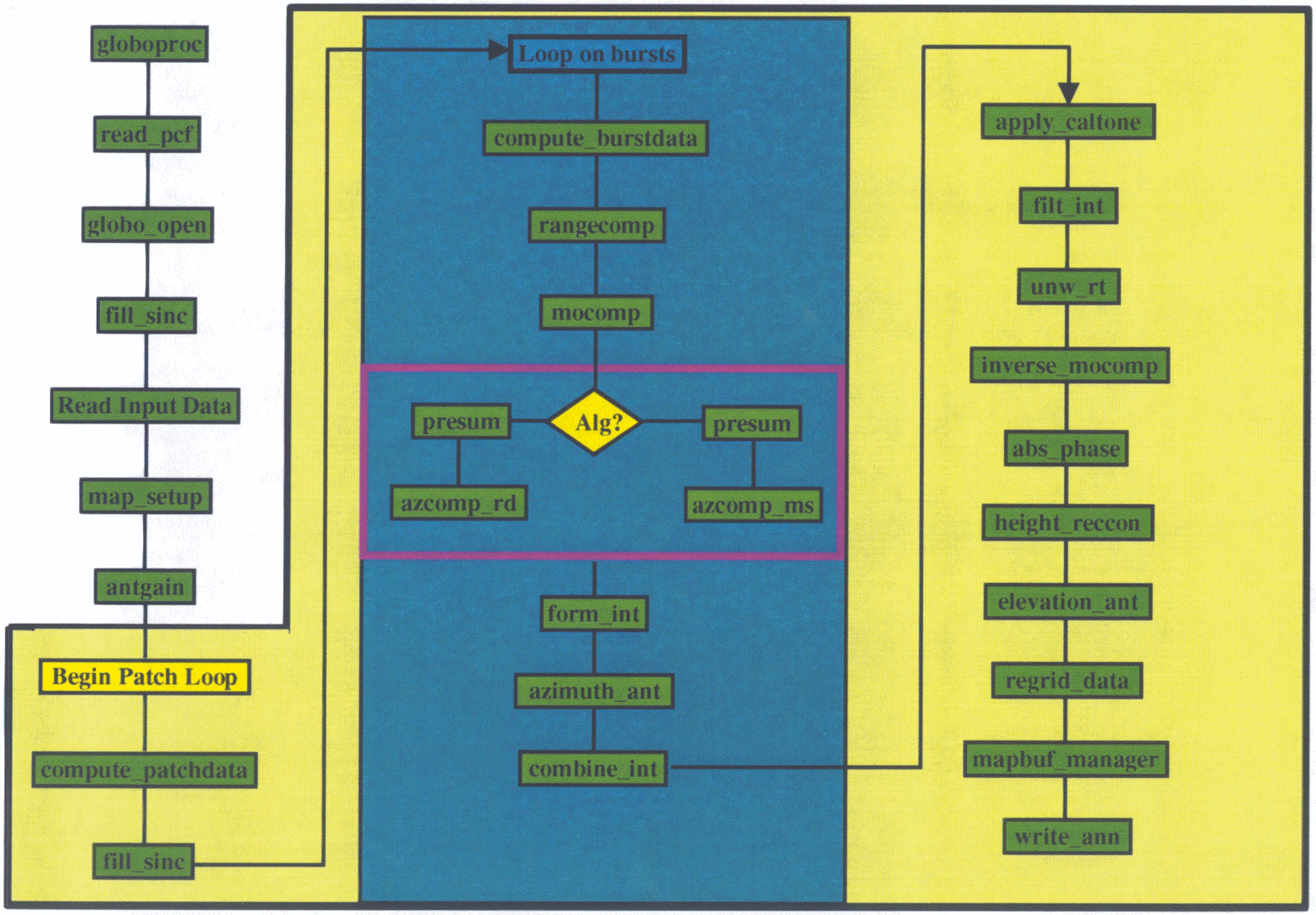
- Mapped region is divided into 5° and 10° latitude bands (≈1500 km of along track distance) where the SCH peg latitude is fixed to a value at the center of the band. Maximal projection height differences from ellipsoidal heights is approximately 40 m.
- Maximal file size for a given subswath is approximately 1.6 Gbytes. This size file can be addressed with either 32 or 64 bit file addressing operating systems.

Data Collection Basics

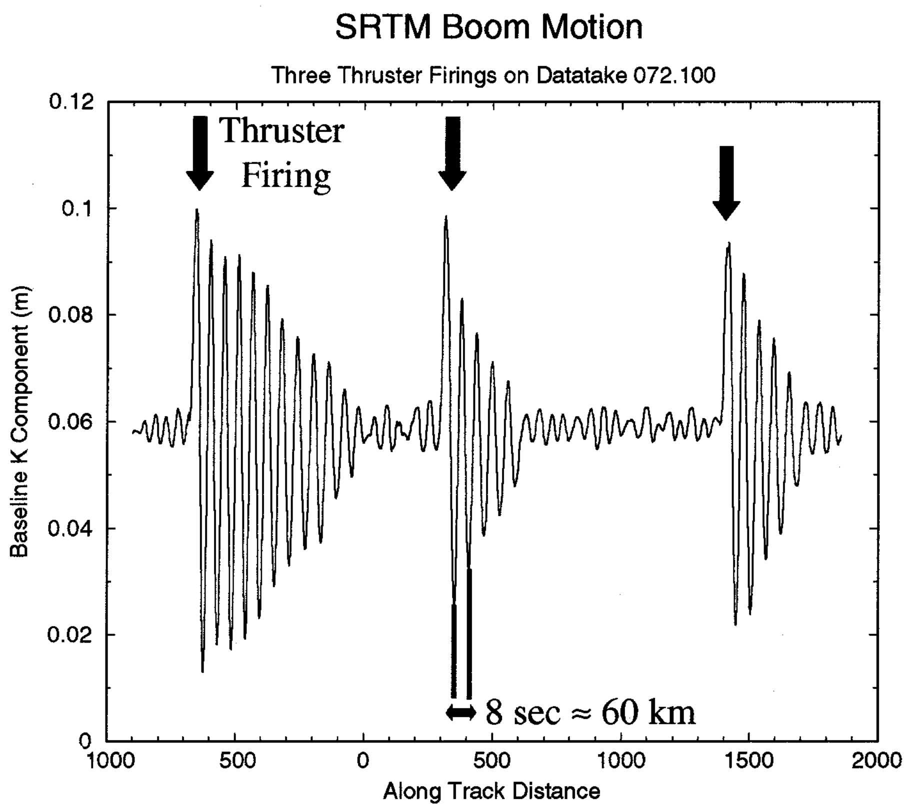
- SRTM collected data in a SCANSAR mode whereby it alternately switched between two beam positions in the cross track direction to increase the swathwidth at the expense of along track resolution. Since SRTM is a polarimetric radar it applied this same procedure to both vertical (V) and horizontal (H) polarizations to achieve an effective swathwidth of 225 km. Each subswath is processed separately into a strip map.



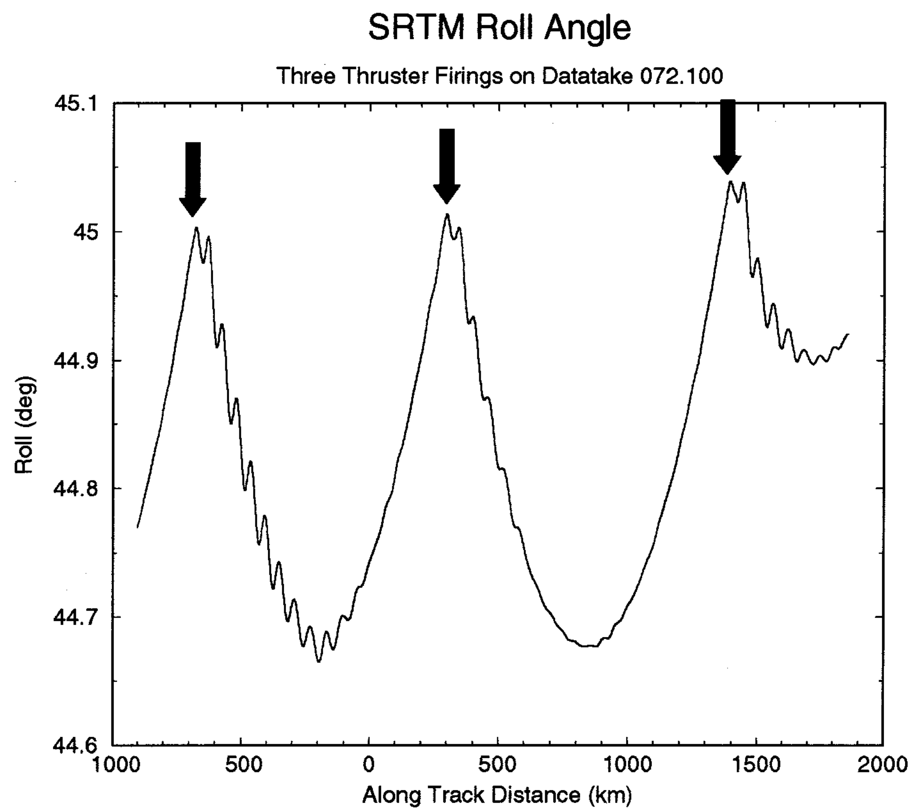
Topographic Processing System



AODA Data and Need for Motion Compensation



Plot of Baseline K Component

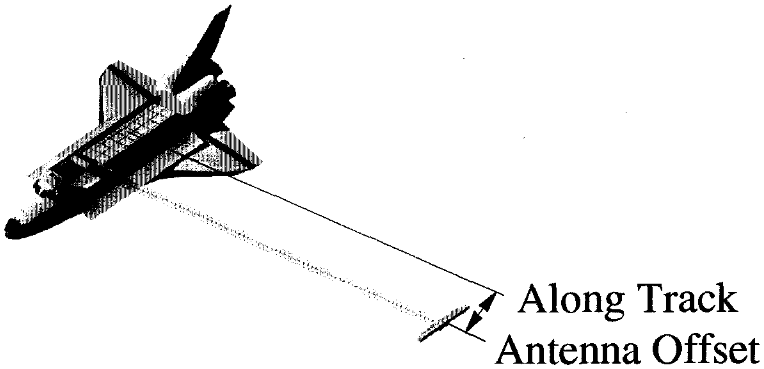


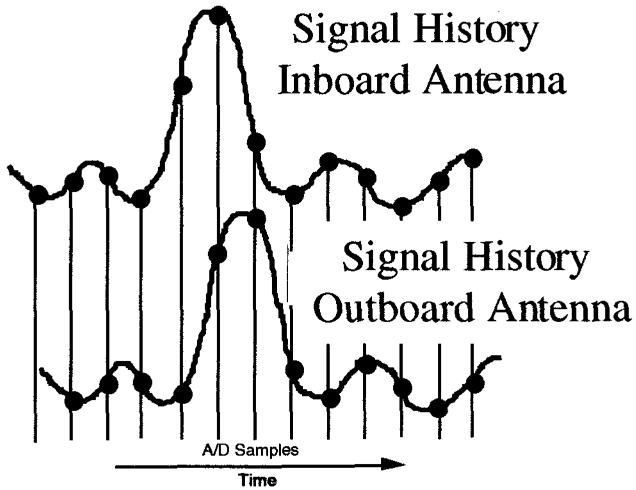
Plot of Roll Angle

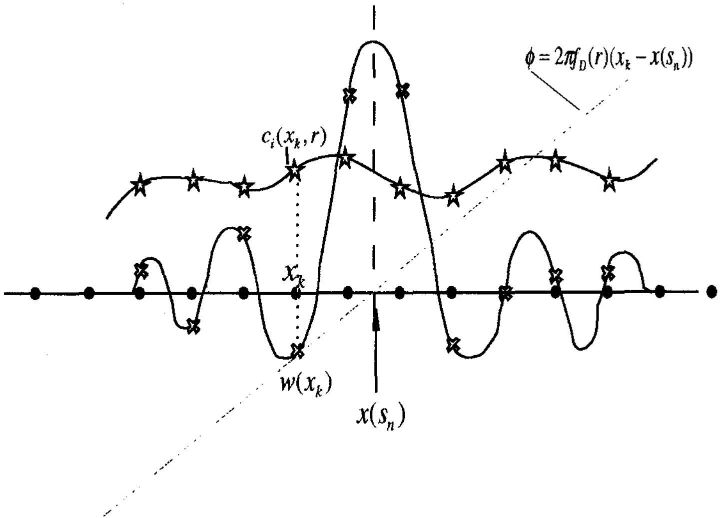
- Motion compensation is required to account for boom dynamics as well as shuttle attitude changes. Left uncompensated these motions would generate hundreds of meters of height error.

Presumming Formulation

- Presumming is used to to resample the phase histories from the two antennas so they are aligned in the along track direction and lie on a uniformly spaced along track grid. Presumming is implemented as a separate module or can coupled as part of the Modified SPECAN azimuth processing







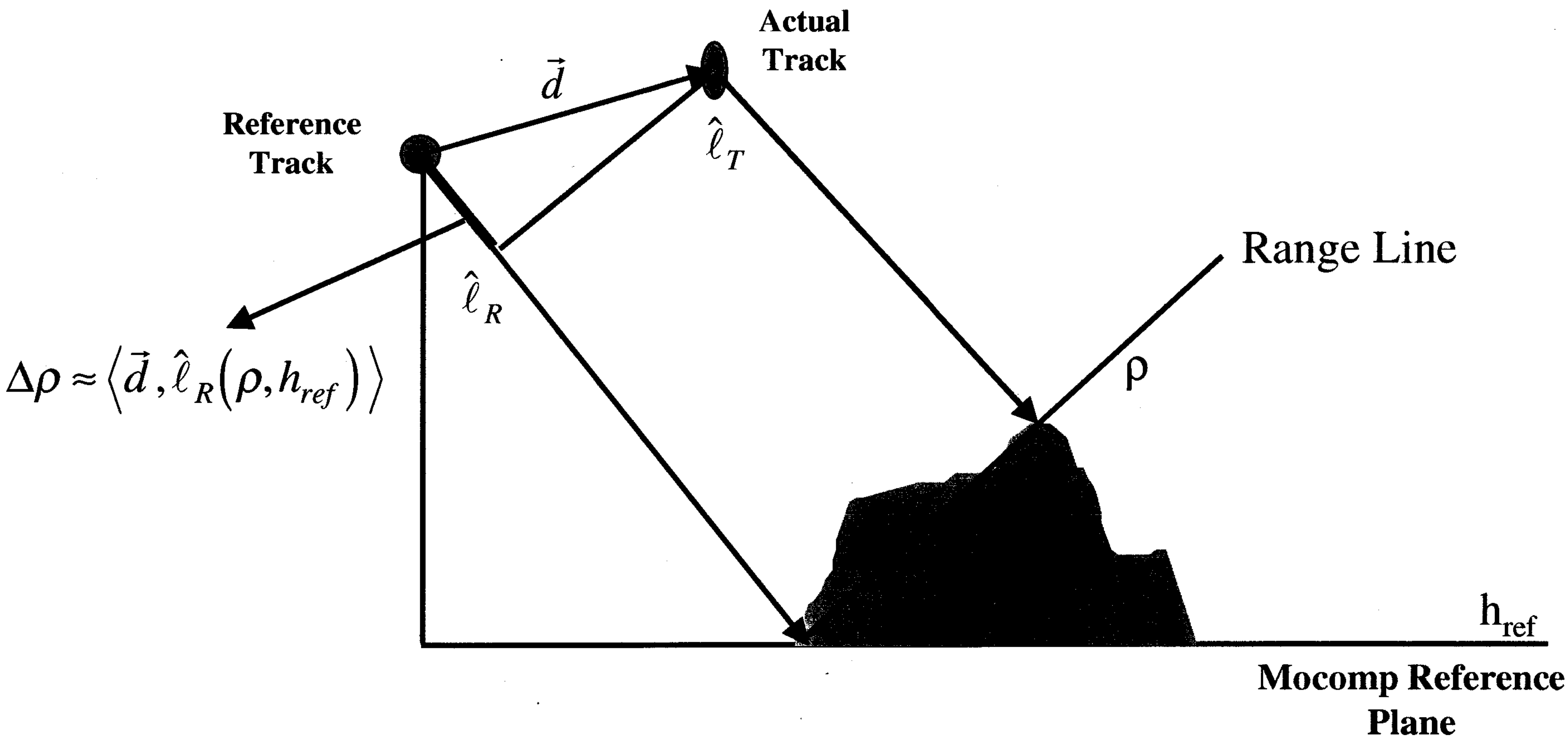
$$c_i'(s_n, r) = \sum_{k=0}^{N_{ps}} c_i(x_k, r) e^{-j2\pi f_D(r)(x_k - x(s_n))} w(x_k - x(s_n))$$

$$f_D(r) = \frac{2}{\lambda} \hat{l}(r) \cdot \mathbf{v}$$

- Presummer is implemented as a weighted bandpass sinc interpolator.

Motion Compensation Geometry

- Motion compensation is used to condition the radar raw signal data to look as if it was collected from an ideal flight path called the reference path. Motion compensation consists of a range shift and phase correction. For SRTM motion compensation directly to a common reference track is used which automatically co-registers the two channels, flattens the fringes, and applies the correct range spectral shift assuming a flat surface.



Burst Processing Algorithms

- Problem:
  - Choose algorithm to perform azimuth compression over the synthetic aperture, taking into account the burst discontinuities in the observing strategy
    - performance accuracy
    - efficiency
    - simplicity and ease of implementation
- Options:
  - Strip-Mode Processing - Standard Doppler processing as though there were no burst strategy employed
  - SPECAN Processing (M. Jin) - Deramp FFT method employed in RADARSAT ScanSAR processor
  - Burst Isolated Doppler Processing
  - Modified SPECAN Processing

Azimuth Compression: Modified SPECAN

Chirp Z-Transform

$$\rightarrow \otimes \rightarrow \boxed{\textit{Azimuth FFT}} \rightarrow \otimes \rightarrow \boxed{\textit{Inverse Azimuth FFT}} \rightarrow \otimes \rightarrow$$

(the middle $\otimes$ is fed from above by a second *Azimuth FFT* block)

$$X_s = \frac{\lambda}{L} r' \quad , \quad \overline{X} = \frac{\lambda}{L} \overline{r}'$$

Range Compressed Burst Signal of Length

$$K = \frac{X_B}{\Delta x'} \quad \rightarrow \otimes \rightarrow$$

$$\exp\left[\frac{2\pi i (k\Delta x')^2}{\lambda r'}\right]$$

Deramp Signal

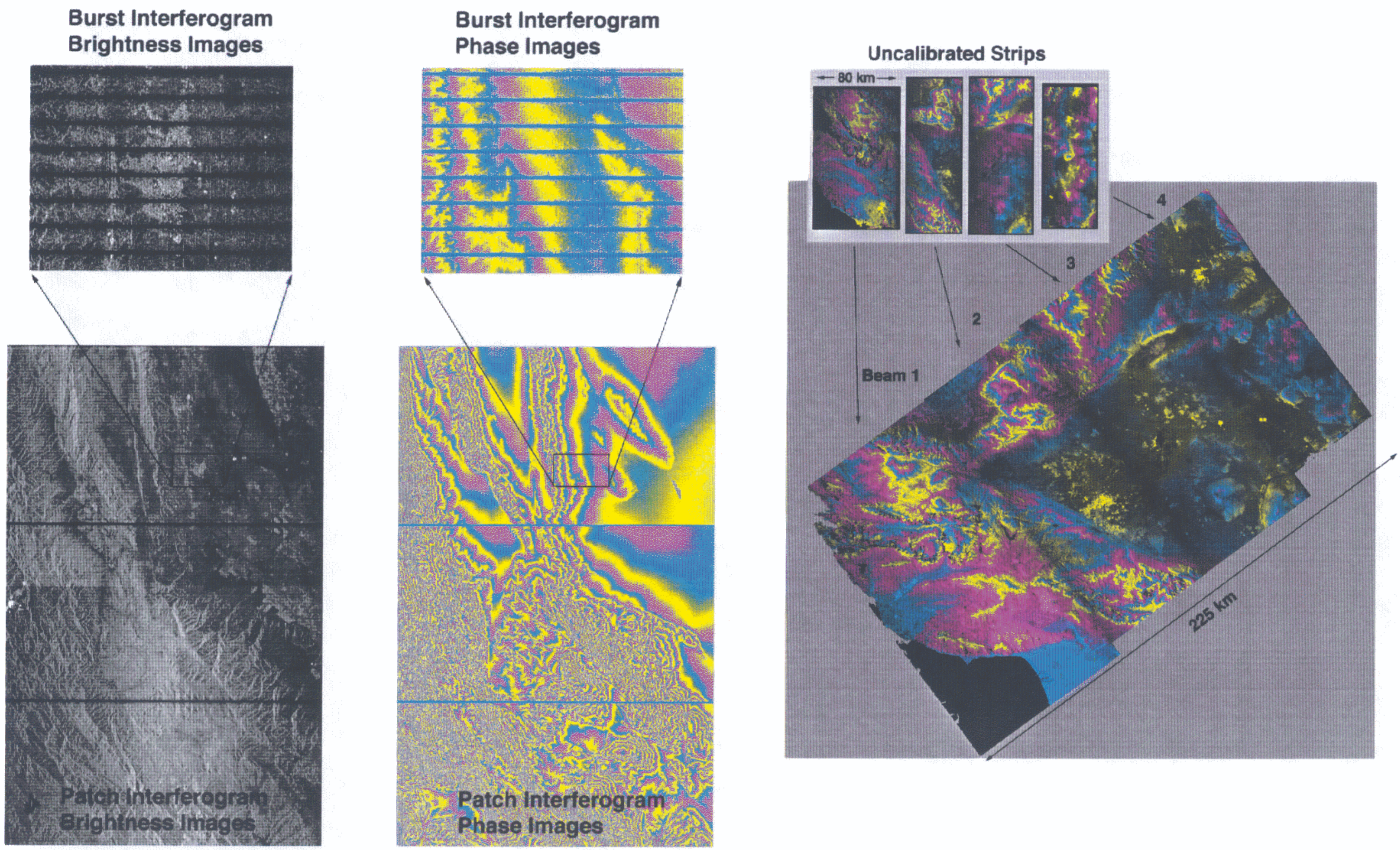
Scaled Azimuth FFT with New Kernel

$$\exp\left[j\frac{2\pi ikn}{K}\right] \rightarrow \exp\left[j^2 \frac{2\pi ikn}{K}\frac{\overline{X}}{X_s}\right]$$

$\rightarrow$ Burst Image With Constant Pixel Spacing

$$\Delta x \frac{X_s}{X_B}\frac{\overline{X}}{X_s} = \Delta x' \frac{\overline{X}}{X_B}$$

TPS SRTM Patch Processing Example

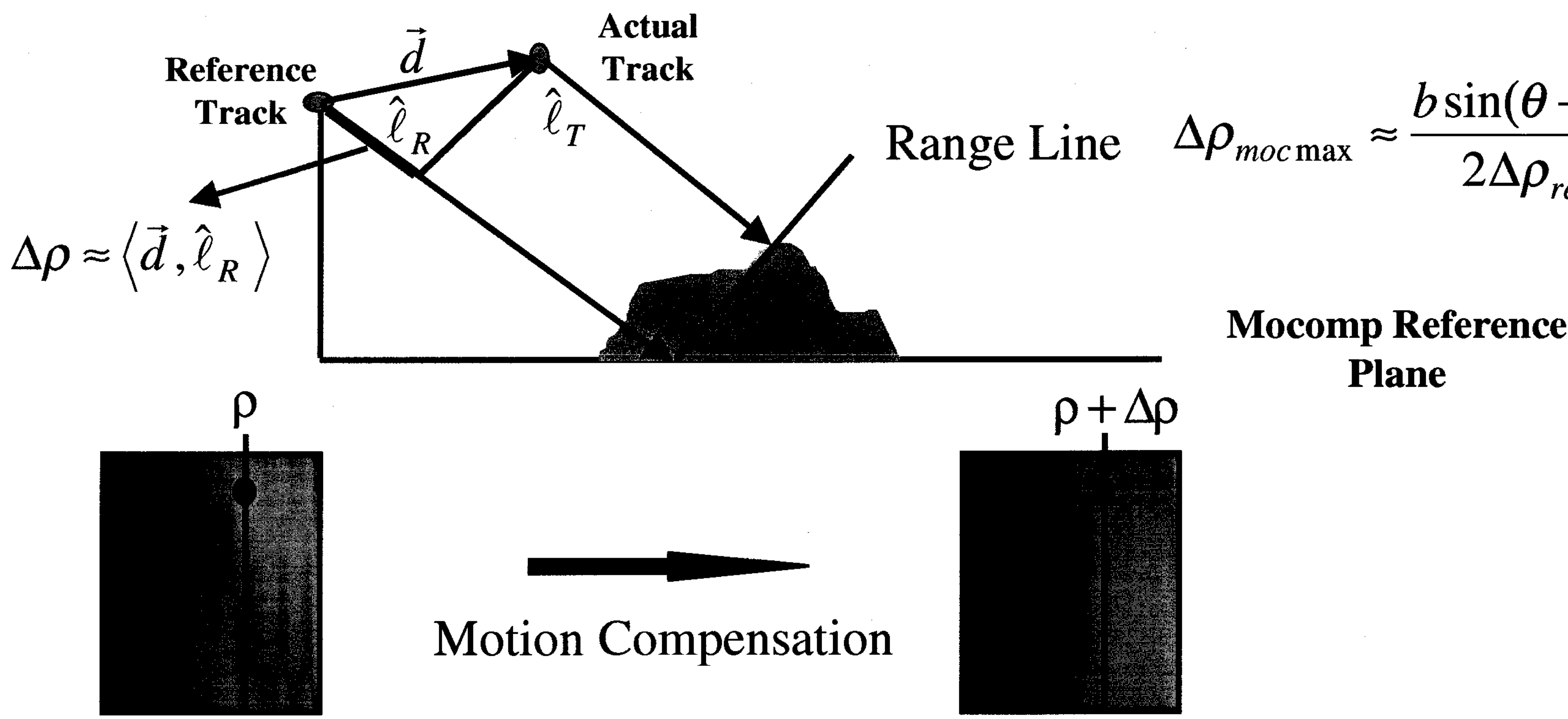


SRTM Interferogram Filtering and Unwrapping

- After formation of the combined patch interferogram can be filtered using either a standard low pass filter or the power spectral filtering technique.
- Unwrapping uses a branch cut algorithm.
  - Absolute "bootstrapped" from previous patch.
  - Correlation mask is used to exclude areas of poor phase quality.
  - Multiple types of neutrons supported for aiding branch cut generation.
    - Phase gradient
    - Radar amplitude
  - Multiple connected components (areas separated by trees or by the correlation mask) are allowed to increase the area that can be unwrapped when bootstrapping phase from previous patch. Components with inconsistent phase with previous patch are masked out to help eliminate unwrapping errors in the final map.

Inverse Motion Compensation

- Inverse motion compensation is used remove the phase applied in motion compensation phase prior height reconstruction.
  - In addition to the phase shift there is an image shift in the range direction equal to the shift in range from the actual flight path to the reference line. Thus the range must also be corrected from the motion compensated range to the actual range.

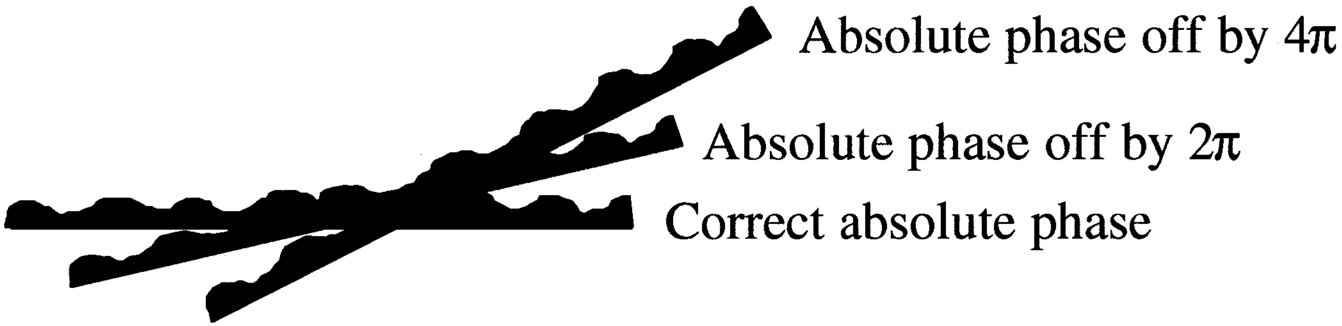


$$\Delta\rho \approx \left\langle \vec{d}, \hat{\ell}_R \right\rangle$$

$$\Delta\rho_{moc\,\max} \approx \frac{b\sin(\theta-\alpha)}{2\Delta\rho_{res}}$$

Absolute Phase Determination

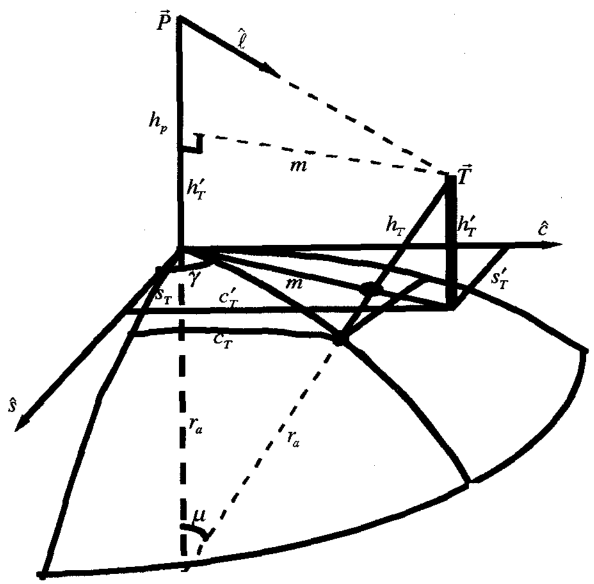
- Over the ocean at the beginning of every datatake will use the known height of the ocean to determine the absolute phase. Ocean height accuracy for absolute phase determination only needs to be about half an ambiguity height (amount of height change for one cycle of phase) which is about 60 m.



- Over land absolute phase determination will use a low resolution DEM (500 m posting) to resolve the absolute phase where such data exists. The low resolution DEM database will be updated with processed SRTM data to fill gaps in the existing database. Database updating will occur after each strip is processed.

Height Reconstruction

- Height reconstruction takes the platform position, velocity, Doppler, range, baseline and interferometric phase of a point and determines its three dimensional location.
  - Algorithm used is exact, i.e. the standard plane wave approximation and any ellipsoid approximations are avoided.
  - Range and phase are corrected for the dry component of the troposphere.
  - Phase is corrected using a "phase screen" to remove any systematic cross track phase distortions that may arise such as from multi-path off the boom or shuttle.



Look vector to point solved from the intersection locus of three surfaces.

- Range sphere $$|\vec{P}-\vec{T}|=\rho$$
- Doppler cone $$f=\frac{2}{\lambda}\langle\vec{v},\hat{\ell}\rangle$$
- Phase cone* $$\phi=\frac{2\pi}{\lambda}\rho\left(\left(1-\frac{2\langle\hat{\ell},\vec{b}\rangle}{\rho}+\left(\frac{b}{\rho}\right)^2\right)^{\frac{1}{2}}-1\right)$$

Regridding Options

- The problem of interpolating data that is not sampled on a uniform grid, that is noisy, and contains gaps is a difficult problem.
- Several interpolation algorithms have been implemented
  - Nearest neighbor - Fast and easy but shows some artifacts in shaded relief images.
  - Simplical interpolator - uses plane going through three points containing point where interpolation is required. Reasonably fast and accurate.
  - Convolutional - uses a windowed Gaussian approximating the optimal prolate spheroidal weighting function for a specified bandwidth.
  - First or second order surface fitting - Uses the height data centered in a box about a given point and does a weighted least squares surface fit.

Adaptive Regridding Parameter Determination

- In the adaptive regridding process it is desired to adjust the amount of smoothing depending on the amount of topography compared to the intrinsic measurement noise.
- The amount of noise reduction and smoothing depends on the size of box used for the regrid point estimate and the amount of weighting employed.
- For computational efficiency is desired to have the weighting depend only on the measurement noise and not vary spatially with the data, however this reduces the flexibility in controlling the amount of smoothing vs noise reduction.
- The box size for fitting is determined by comparing the χ^2 residual of the surface fit to the mean of the estimated height noise as determined from the correlation in the box.
  - large residuals compared to the intrinsic noise level means that surface fit is not a good model for the local topography and therefore a smaller box size should be use.
  - each box size must be checked to insure that the points within the box the correct geometric distribution as needed by the algorithm employed.

Radiometric Compensation

- Radiometric correction is done in four steps
  - Compensation for range squared amplitude reduction is applied after range compression.
  - Azimuth antenna pattern correction is applied for each burst after azimuth compression.
  - Elevation antenna pattern correction is applied after height reconstruction.
  - Correction for the area projection factor is applied during regridding (an option for area reprojection with a constant incidence and illumination angle is also available)

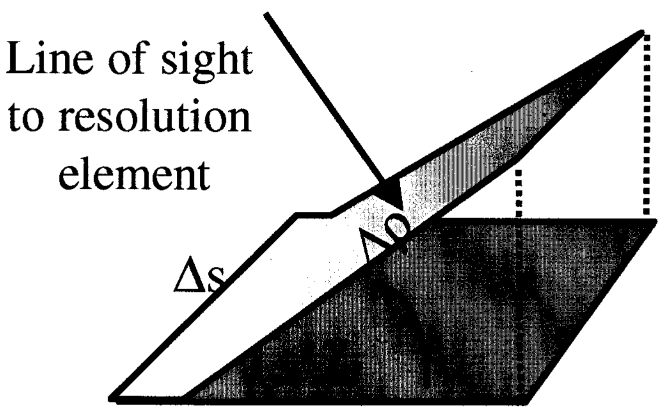
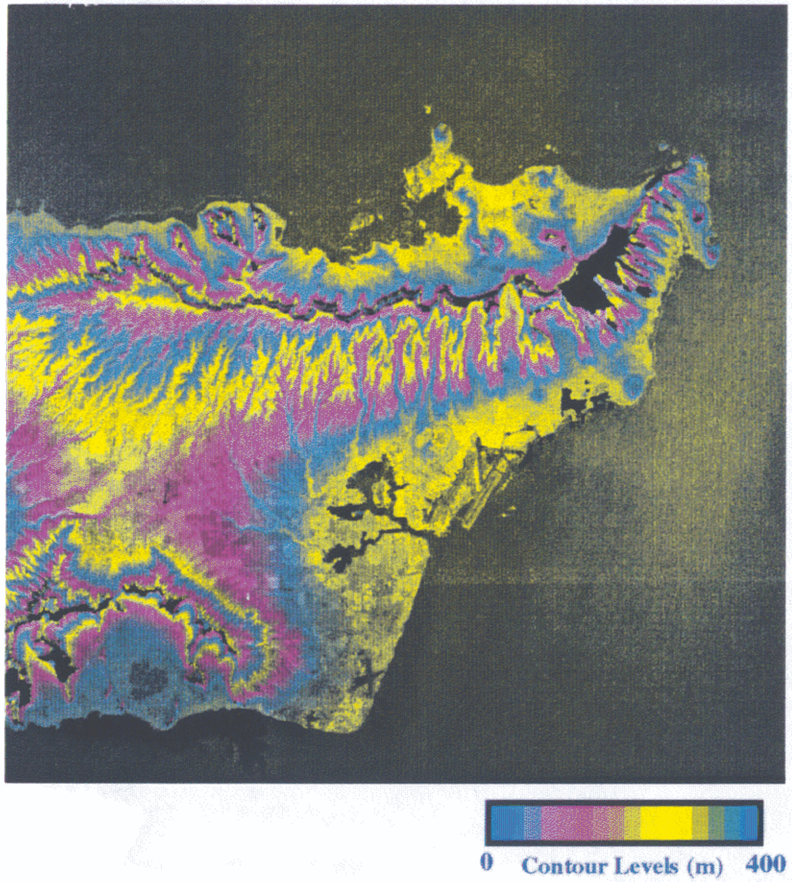


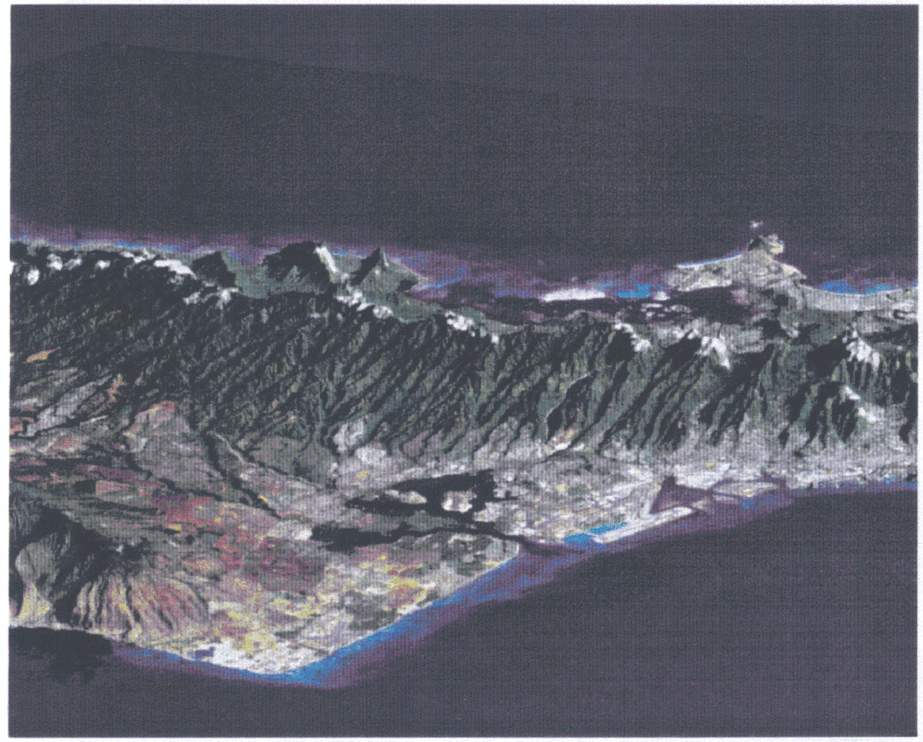
Image brightness corrected by the amount of ground area seen by the radar for each resolution element.

$$A = \frac{\Delta\rho\Delta s}{\langle \hat{n}_\Sigma , \hat{n}_I \rangle} = \frac{\Delta\rho\Delta s\sqrt{1-\sin^2(\gamma_c)\sin^2(\gamma_s)}}{\sin(\theta-\gamma_c)\cos(\gamma_s)}$$

A is the area the on the ground responsible for the scattering where $\Delta\rho$ and Δs are the range and along track resolution element dimensions and γ_c and γ_s are the cross track and along surface tilts respectively.

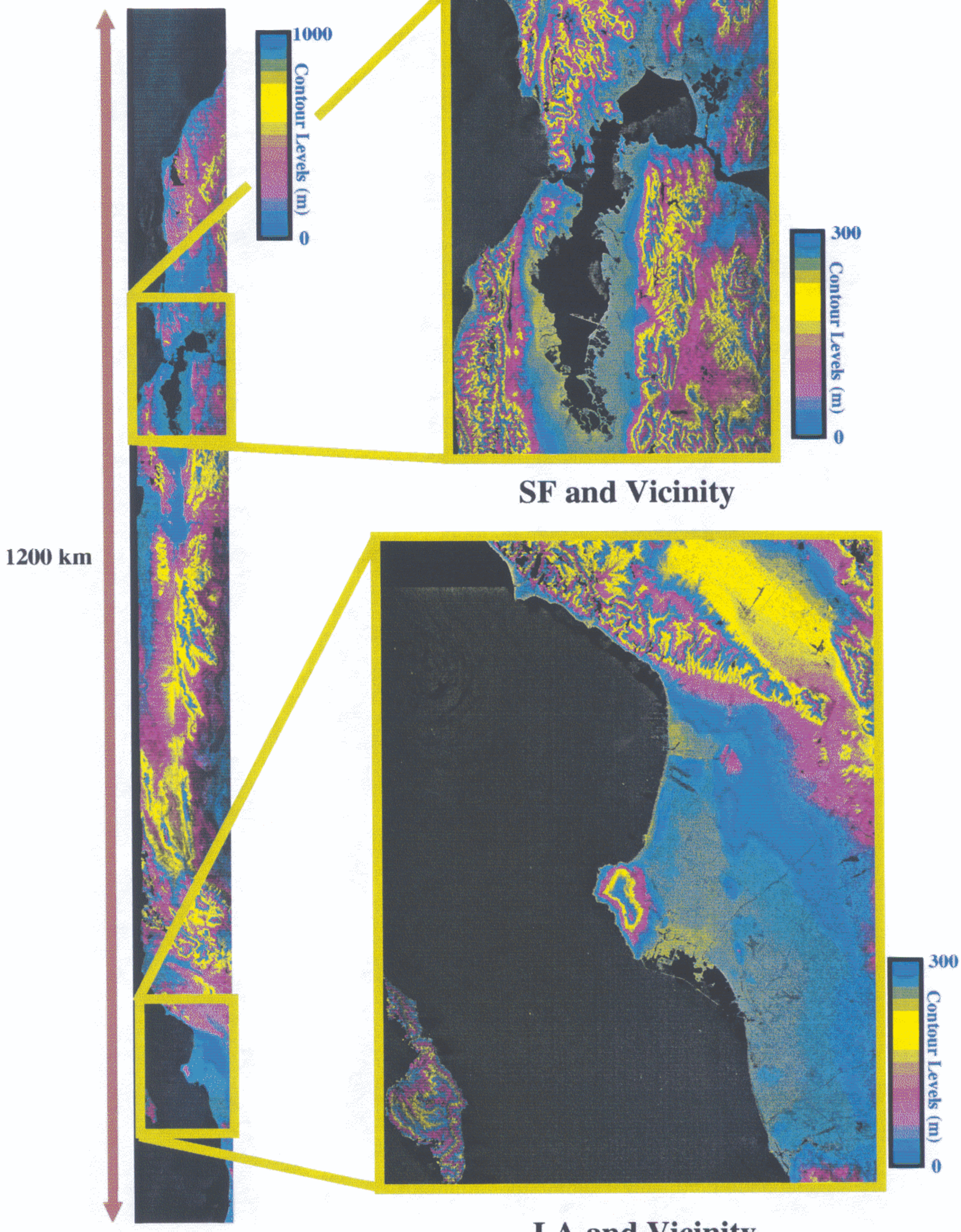
Hawaii Images





- Image of Oahu generated during the mission (3 am PST) showing the radar backscatter with color elevation contours overlain. The right image uses the SRTM DEM and Landsat imagery to generate a perspective view.

California Images



Conclusions

- SRTM C-Band was designed as a flexible processor capable of supporting calibration and production of strip map products.
  - End-to-end ScanSAR interferometric processor.
  - Multiple interferogram filtering and regridding options.
- Processor currently being used for system calibration and will transition to production use at end of this year.